Director's Review of Initiatives in Neutrino Physics

Janet Conrad & Bill Louis

June 9, 2004

Charge 2: If the LSND result is confirmed by the results from MiniBooNE, neutrinos do not fit the standard picture of three neutrino flavors with full weak coupling. How might the neutrino program evolve as results appear from MiniBooNE?

- Louis Description of MiniBooNE Complex & Capabilities
- Louis Scenario 1: MiniBooNE Sees a Signal in Neutrino Mode
- Conrad Scenario 2: MiniBooNE Sees No Signal In Neutrino Mode, but Does See a Signal in Antineutrino Mode
- Conrad Scenario 3: MiniBooNE Sees No Signal in Neutrino Mode & Is Turned Off

MiniBooNE Complex & Capabilities

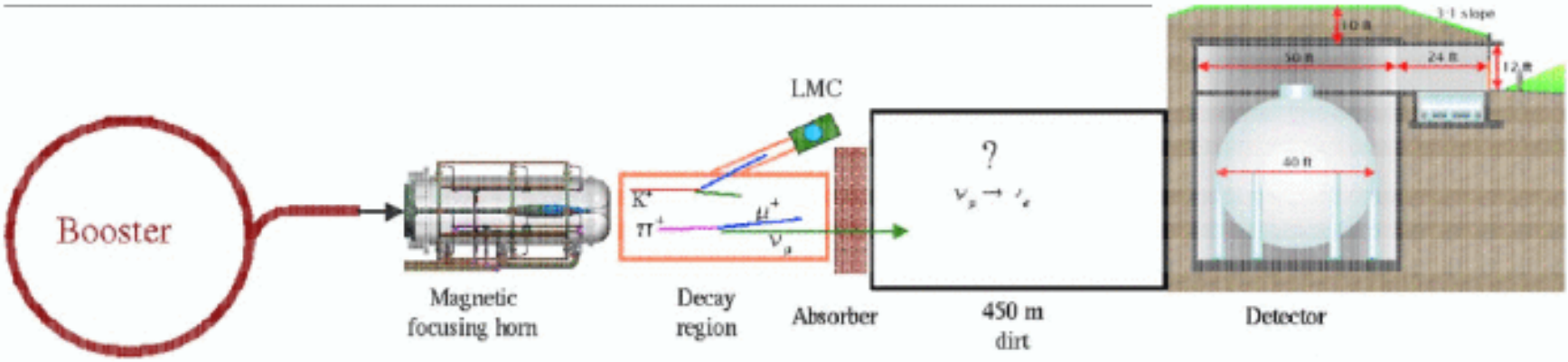
The Booster Beamline is the World's Best SBL Neutrino Beam!

The Booster Beamline is now providing > 8 x 10^{18} POT/week!

The Booster Beamline Can Continue to Operate in the NuMI Era!

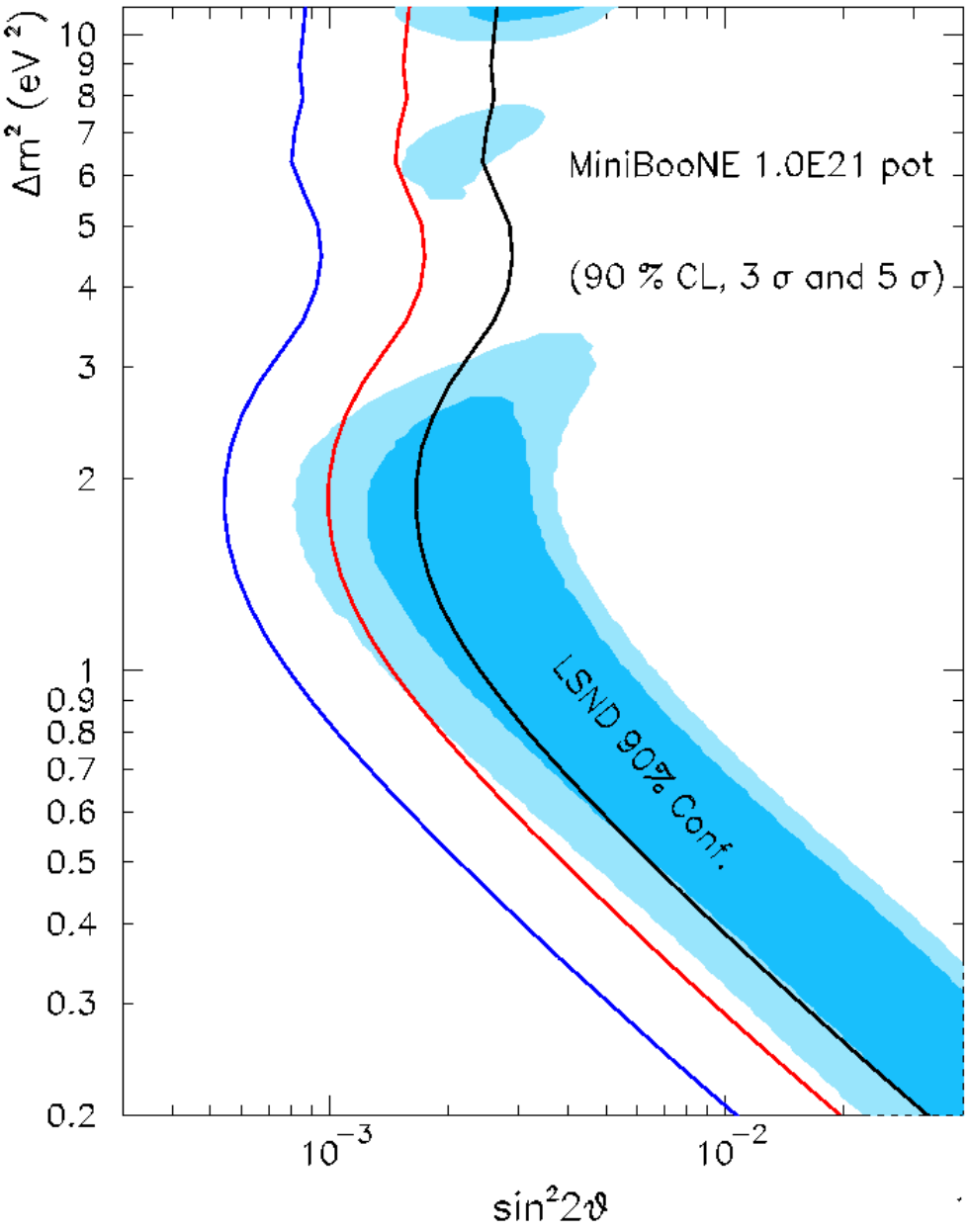
MiniBooNE Site Layout

MiniBooNE - A Definitive Test of the LSND Evidence for ν Oscillations

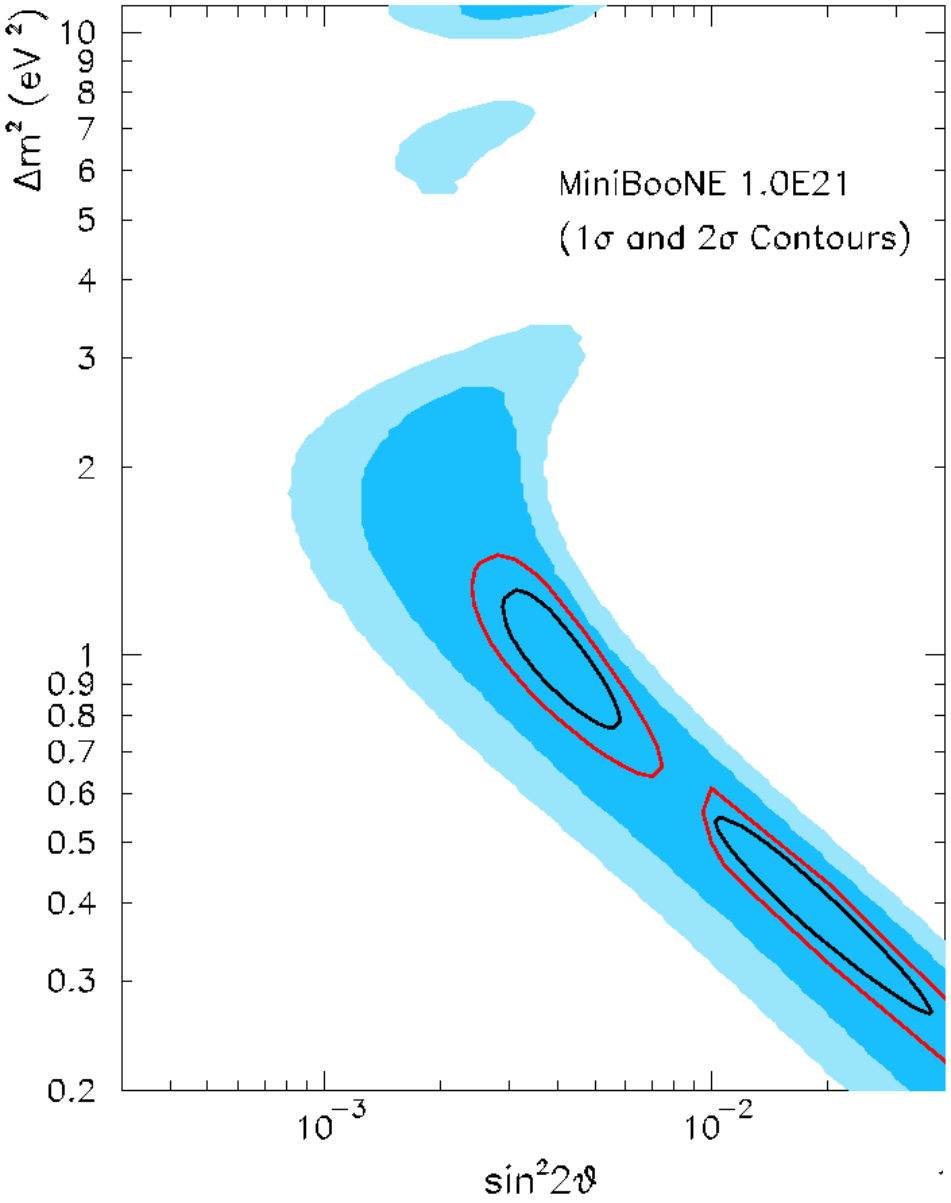


- Booster - 8 GeV proton beam (5 x 10^{20} POT/y)
- Target - 71 cm Be
- Horn - 5 Hz, 170 kA, 143 μs, 2.5 kV, 10^{8} pulses/y
- Decay Pipe - 50 m (adjustable to 25 m)
- Neutrino Distance - ~ 0.5 km
- $\langle E_\nu \rangle$ ~ 1 GeV
- (ν_e / ν_μ) ~ 5×10^{-3}
- Detector - 40' diameter spherical tank
- Mass - 800 (450) tons of mineral oil
- PMTs - 1280 detector + 240 veto, 8" diameter

Expected MiniBooNE Sensitivity

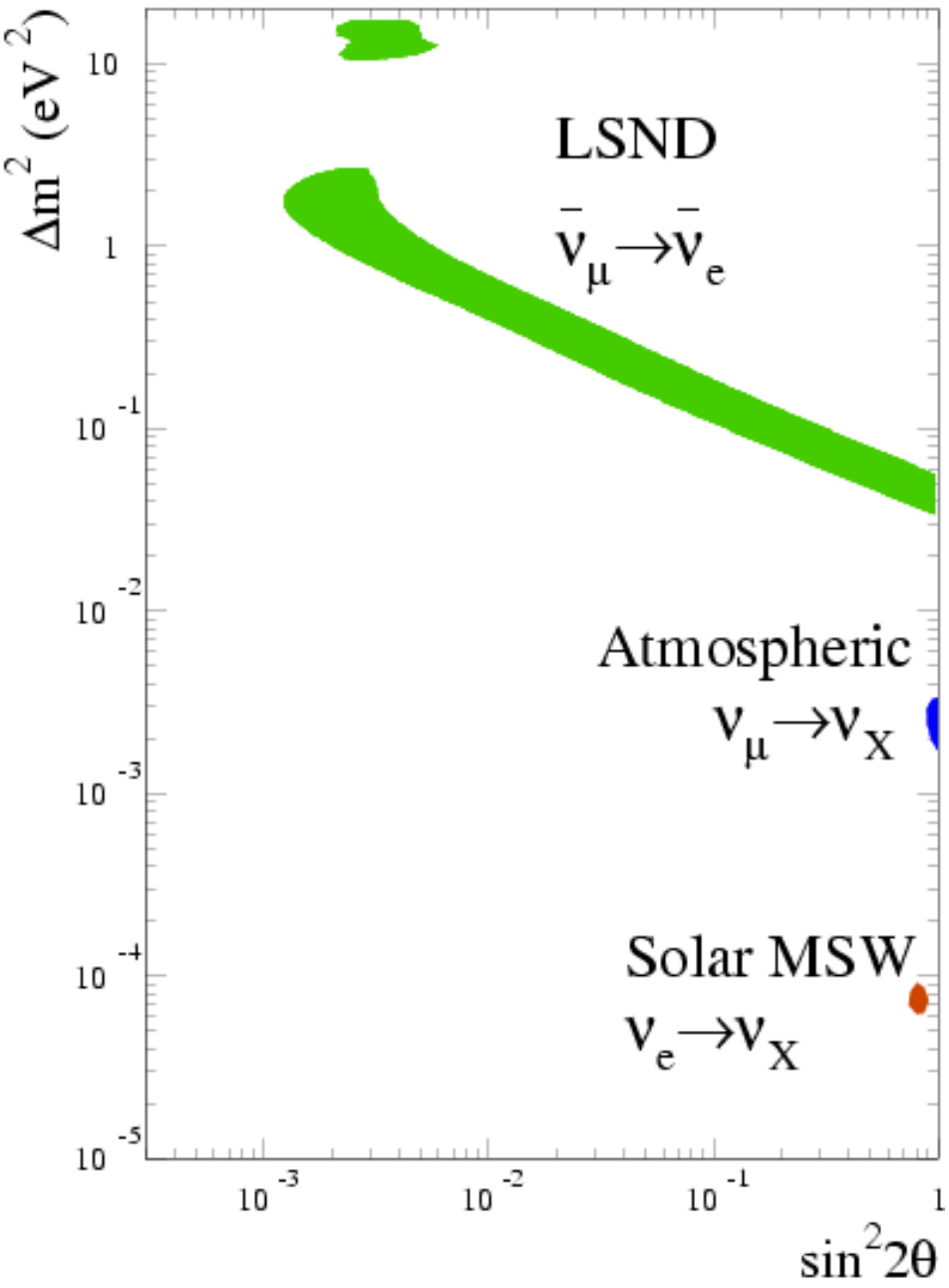


Measurement of Oscillation Parameters



With 5E20 POT,
we cannot distinguish Δm^2 !

Current State of Neutrino Oscillation Evidence



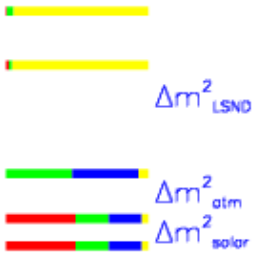
Expt.	Type	Δm^2 (eV^2)	$\sin^2 2\theta$
LSND	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	~1	~3×10^{-3}
Atm.	$\nu_\mu \rightarrow \nu_\tau$	~2×10^{-3}	~1
Solar	$\nu_e \rightarrow \nu_{\mu,\tau}$	~7×10^{-5}	~0.8

Scenario 1: MiniBooNE Sees a Signal in Neutrino Mode

If MiniBooNE sees a signal in neutrino mode, then, together with solar and atmospheric data, it will imply
Physics Far Beyond the Standard Model!

For example, theories with large neutrino-mode signal:

3+2 Sterile Neutrinos — Sorel, Conrad, & Shaevitz hep-ph/0305255



2 Δm^2 with roughly same magnitude.
Goodness of fit 30%

R-Process in Supernovae?

MaVaNs — Fardon, Nelson, & Weiner astro-ph/0309800
Kaplan, Nelson, & Weiner hep-ph/0401099

mass varying neutrinos

Explain Dark Energy?

Physics Goals to Pursue

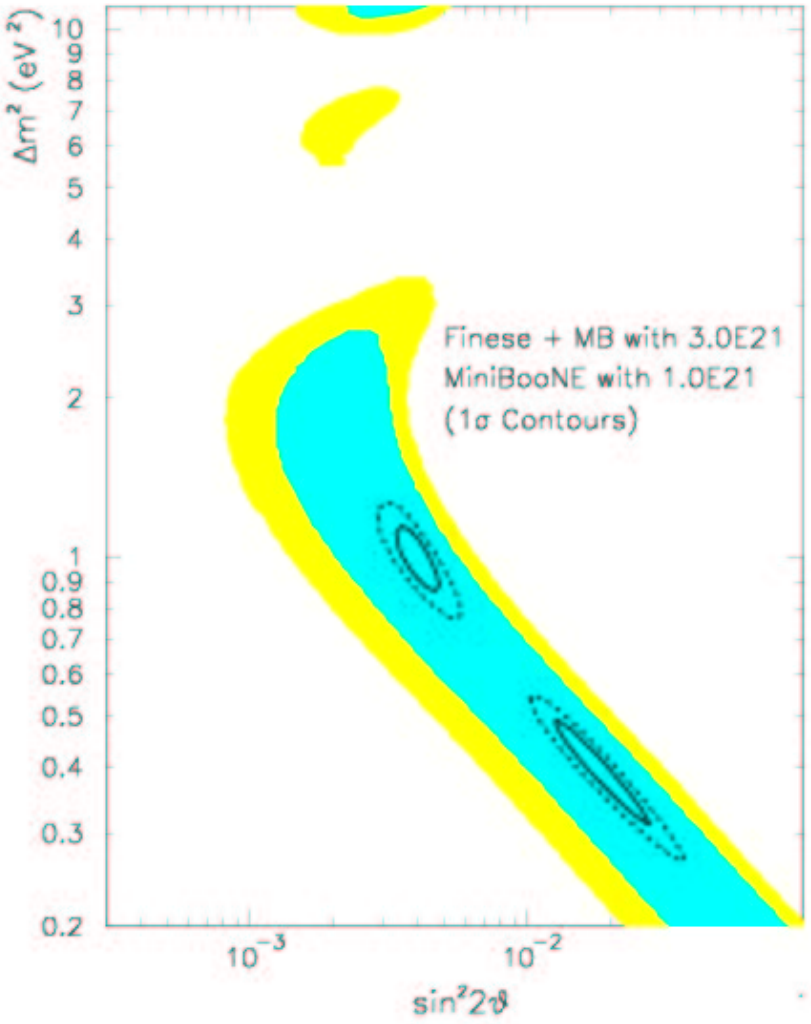
- An exciting short baseline physics program with room for many experiments at many facilities!
- Measure $\nu_\mu \rightarrow \nu_e$ parameters more precisely
- Search for ν_μ disappearance, **large** in 3+N models
- Search for ν_τ appearance
- Check if neutrino and antineutrino oscillation parameters are the same (CP or CPT violation? see scenario 2)
- Search for more than one Δm^2

BooNE Physics Program

- Build 1 or more BooNE detectors at different distances (e.g. a FINeSSE detector (**~$5M**) at 100 m and a far detector (**~$8M**) at 1000 m)
- Run with both neutrino and antineutrino beams
- Search for ν_μ disappearance via NC and CC to test for active neutrino and sterile neutrino mixing.

MiniBooNE + small near detector

~$5M (fully loaded including civil)



T2K Near Detector Complex can probably do similarly well.

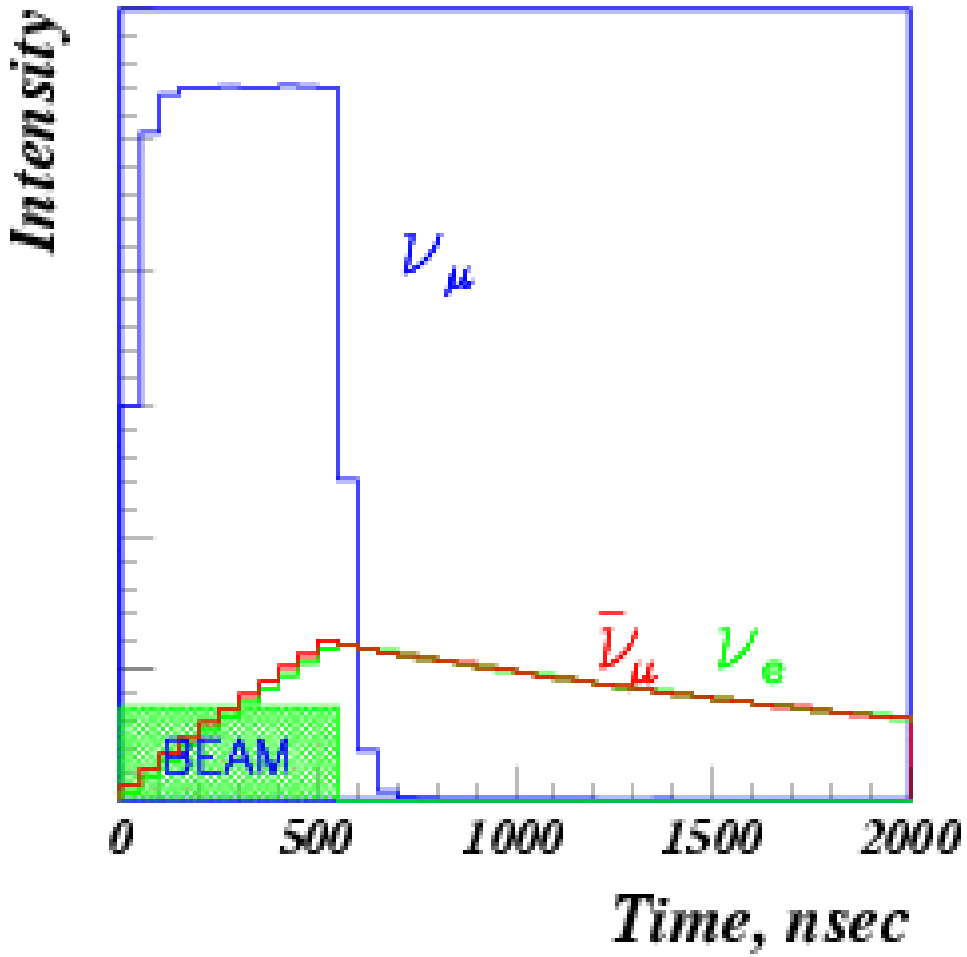
An additional large detector (~$8M) reduces errors by ~× 2

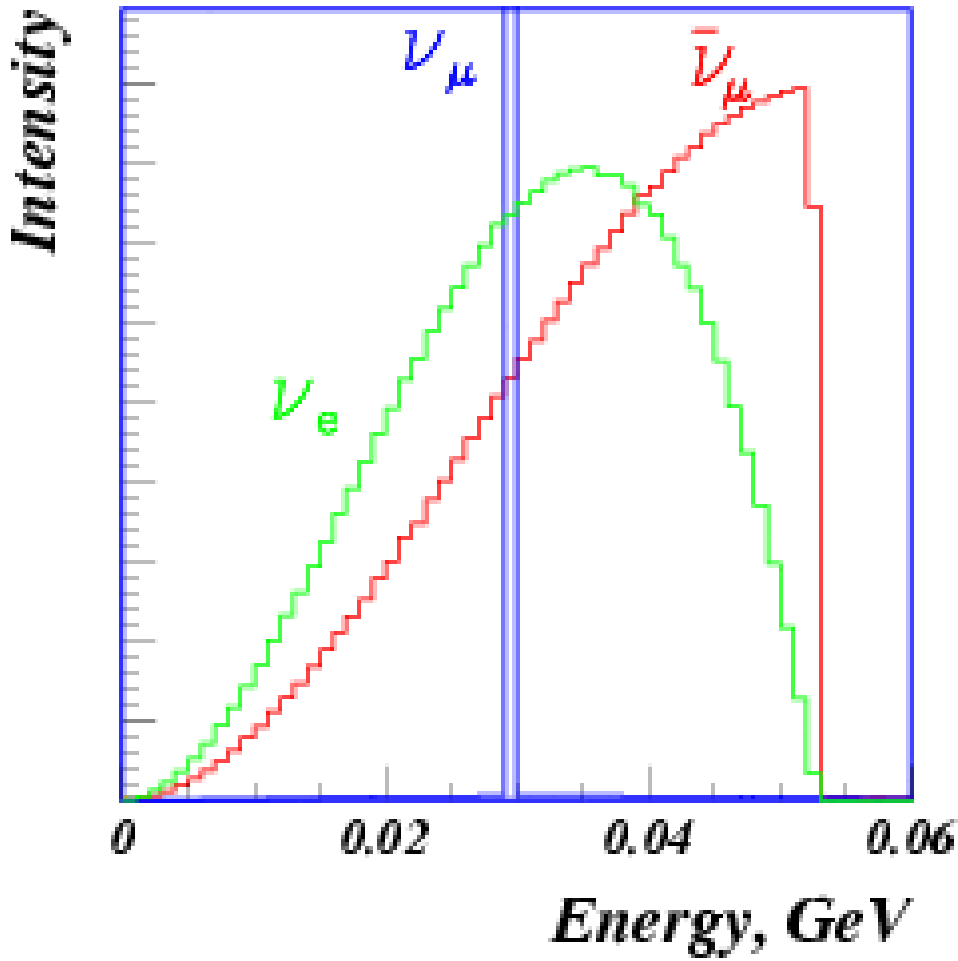
A Stopped Beam Program at SNS

(or possibly at an FNAL proton driver)

- Build a MiniBooNE-like detector (**~$12M**) at the SNS (**1.4 MW!**)
- Monoenergetic ν_μ from π^+ decay & $\bar{\nu}_\mu$, ν_e from μ^+ decay
- Measure $\nu_\mu \rightarrow \nu_e$ & $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations
- Search for ν_μ disappearance with the ν C -> ν C*(15.11 MeV) NC reaction to test for sterile neutrino oscillations
- High oscillation signal & very low backgrounds (S/B ~ 10)
- Flux shapes are known perfectly and cross sections are known very well (< few%) : ν C -> ν C*(15.11 MeV), ν e -> ν e, $\bar{\nu}_e$ p -> e^+ n, ν_e C -> e^- N_{gs}

SNS Time & Energy Spectra





Other Short Baseline Possibilities

I. Reactors

Two or more near detectors at different distances

- **One close to the reactor @ ~30 m (cf. Bugey)**
- **excellent if large mixing, small Δm^2 is LSND solution**

Measure $\bar{\nu}_e$ disappearance

II. BNL

Can vary proton energy from 3 to 20 GeV

Room for two or more detectors at different distances

Tom Kirk has requested a proposal in autumn for near detector

Long Baseline Physics Program

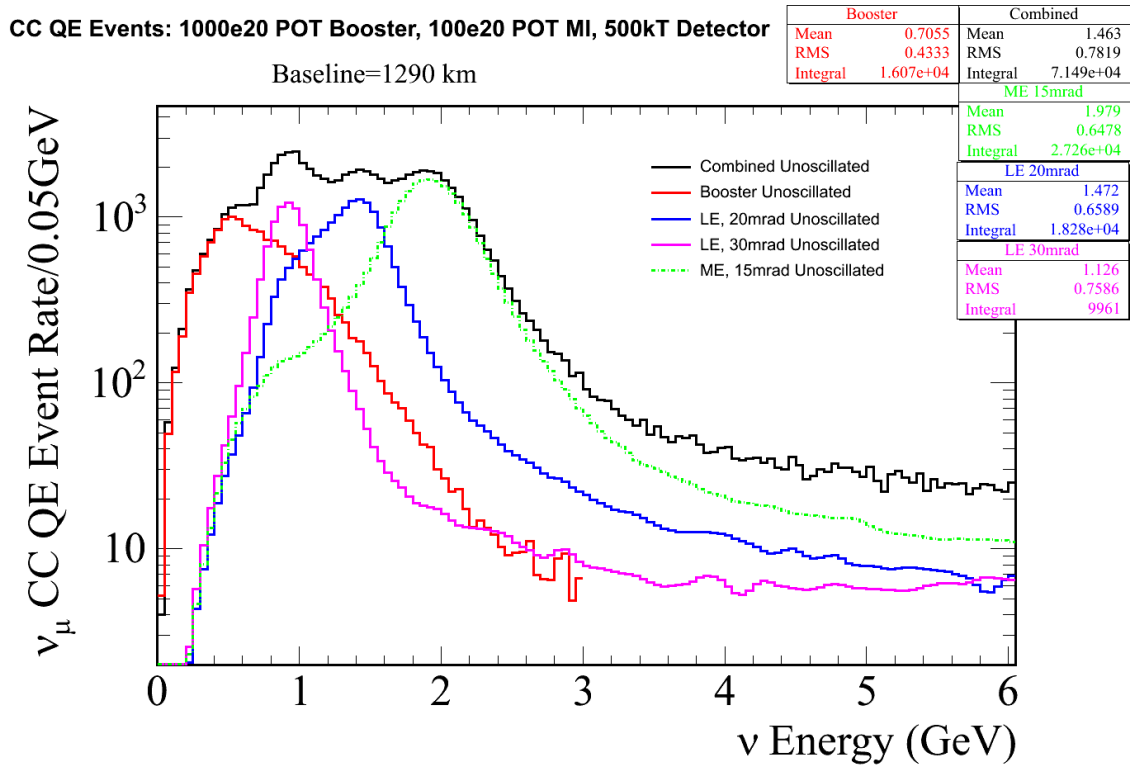
- Minos, Nova, Reactor Experiments, CNGS, T2K, & BNL
- Good News: The MiniBooNE signal entails additional oscillation physics to explore!
  - May be exciting sterile & active ν studies for Minos & T2K!
- Bad News: MiniBooNE signal will be a background for θ_{13} measurements (to be discussed in Scenario 2)
- **A Proton Driver will be needed to disentangle all of the oscillation signals!**
  - High statistics
  - Ability to run multiple distance-scale studies

The 8-&-120 GeV Proton Driver Option

from talk by D. Michael, BNL Superbeams working group meeting:

can provide
short,
long and
very long
baseline beams,
with tunable energy

The VLBL program would be at least as good as the BNL proposal



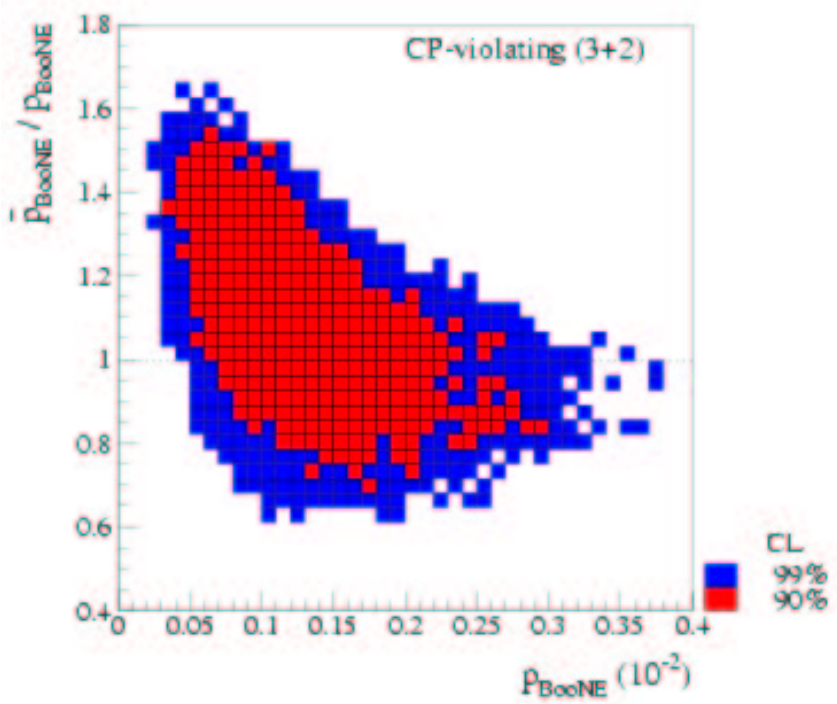
Scenario 2

MiniBooNE sees
no signal in
Neutrino Mode

but
sees a signal in
Antineutrino Mode.

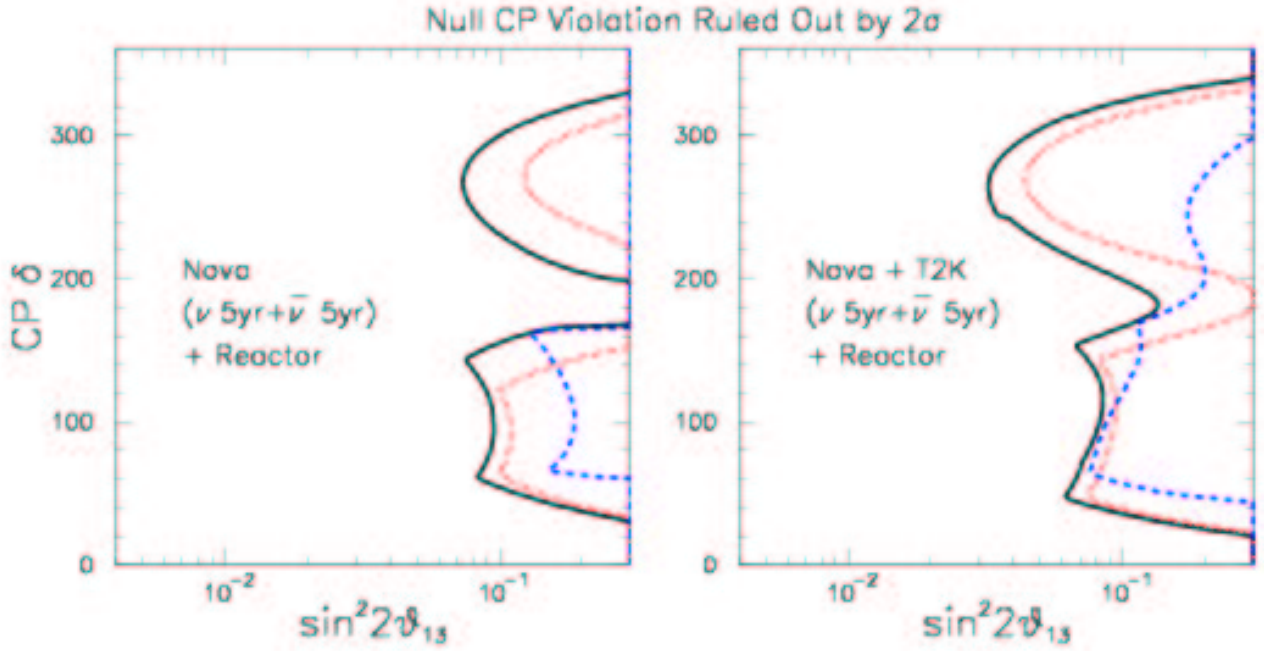
CP Violation

$$\mathbf{P_{osc}}(\nu_\alpha \rightarrow \nu_\beta) \neq \mathbf{P_{osc}}(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$$



Sorel and Whisnant, preliminary

Potential effect on Nova



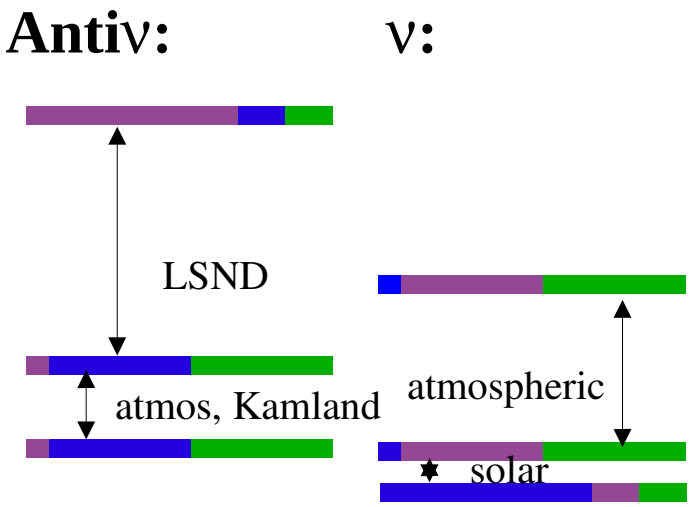
Black: Nova sensitivity for no LSND signal

Red: Sensitivity for LSND CP conserving signal

Blue: Sensitivity for a CP violating signal with $P_{osc}^{LSND} = 0.02$

(this is worst case)

CPT Violation



Mass Spectrum Model:
hep-ph/0210411 Barenboim, Lykken

disfavored unless steriles are also invoked

Lorentz Invariance Violation:
Kostelecky and Mewes, hep-ph/0308300

Fits to neutrino data can, in principle, accommodate an LSND signal

Quantum Gravity Decoherence Model:
Additional mixing induced by singular space-time configurations
(wormholes, microscopic black holes, geons = "space time foam")

fit to data: χ^2/DOF = 60.7/56 hep-ph/0404014, 0406035 Barenboim, Mavromatos

Followups to Scenario 2

Essentially the same followup program as for scenario 1

- Install near detector at FNAL
- Build BooNE at FNAL
- Run the stopped muon beam detector
- Upgrade FINeSSE@ BNL and run in νbar mode
- Run T2K with antineutrinos and use the near detectors

Capability of Minos to address the sterile neutrino mixing matrix content needs to be studied ... may be exciting!

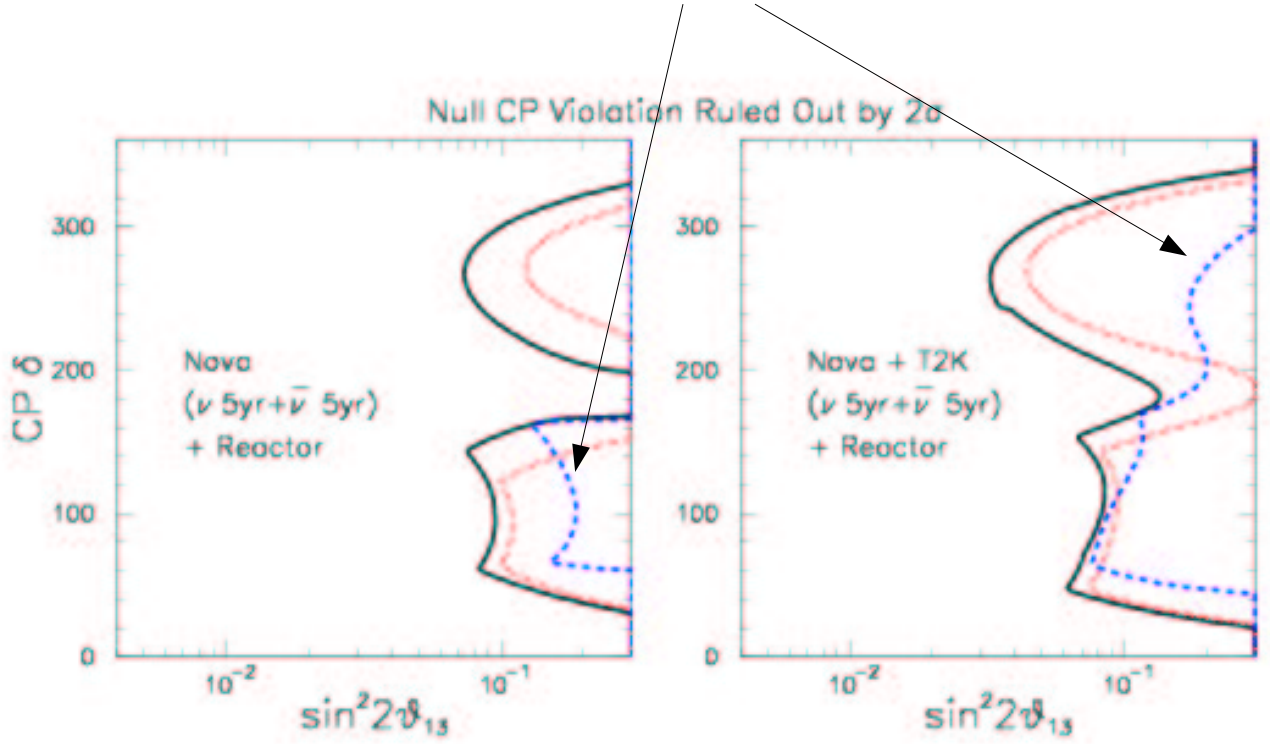
Scenario 3

MiniBooNE sees
no signal in
Neutrino Mode
and
Fermilab Directorate
"sunsets" the experiment.

This would be a mistake.

You may miss an opportunity for a major discovery.

You will hobble your proposed program because you will have to assume LSND as a systematic error



As a result, a conclusion of the APS Neutrino Study is that MinibooNE antineutrino running is crucial to the field.

Antineutrino running will be noted as a priority in the final APS Study Report.

Final Thoughts

Nu-signal Map

Red = mass question,
Blue=sterile question

	Fermilab	World-wide
2005	MiniBooNE nbar run	
	Design BooNE	
	If you had FINeSSE at this point, you could modestly address steriles	short-baseline reactor experiment
	Build BooNE	FINeSSE @ BNL upgraded with second detector. Can do E scan from 3 to 20 GeV pot
2010	BooNE starts	
	BooNE does precise L/E measurements. A near detector would allow for ν_μ disappeareance	Combo of 200m and 2 km T2K near detectors provide another L/E and disapp measure SNS far detector precision L/E & disapp @ high Δm^2
2015		Run precision ν_s & ν_τ experiment???

an 8-&-120 GeV program would nail the question

Nubar-signal Map

Red = mass question,
Blue=sterile question

Fermilab

World-wide

2005

MiniBooNE nbar run

MiniBooNE nbar results

Start building SNS

2010

Design BooNE
while MiniBooNE
runs for even more statistics

Combo of 200m
and 2 km
T2K near detectors
checks result running
in nbar (means a shift
of schedule for nbar run?)

SNS far detector
precision L/E
& disapp @
high Δm^2

Build BooNE

2015

FINeSSE @ BNL
upgraded with second detector.
Can do E scan from 3 to 20 GeV pot

BooNE starts using proton driver

We Need A Proton Driver Somewhere!

In the end, if MiniBooNE sees a signal, a proton driver will be necessary to obtain the statistics to sort it out.

There are a lot of other good reasons to build a Proton driver

Many sites would like to host a Proton Driver in the U.S.

In order to be a viable candidate for the Proton Driver:

a site must build the confidence of the neutrino community that they can deliver a competitive physics program.

A Great Scenario for FNAL

now-2015: Run MiniBooNE and BooNE
Run Minos
Run a lively program of other small experiments
wanting to use these beams

Post-2015 (Proton Driver):
Build the 8-and-120 GeV option
Which allows short, medium and long baseline expts.

This scenario will be successful whether or not MiniBooNE sees a signal.

This scenario propels Fermilab to the forefront of Neutrino Physics
at the end of the 2010's

It isn't the lab which confirms the anomaly
that will get all of the accolades.
It's the one that figures out the physics.

Carpe Diem!

Backup slides

SNS Signal & Backgrounds

- Signal: $\bar{\nu}_e$ p -> e^+ n, n p -> d γ (2.2 MeV)

  For LSND parameters, expect ~350 oscillation events per year! (x2 more ν & x5 more mass)

- Background: $\bar{\nu}_e$ p -> e^+ n, n p -> d γ (2.2 MeV)

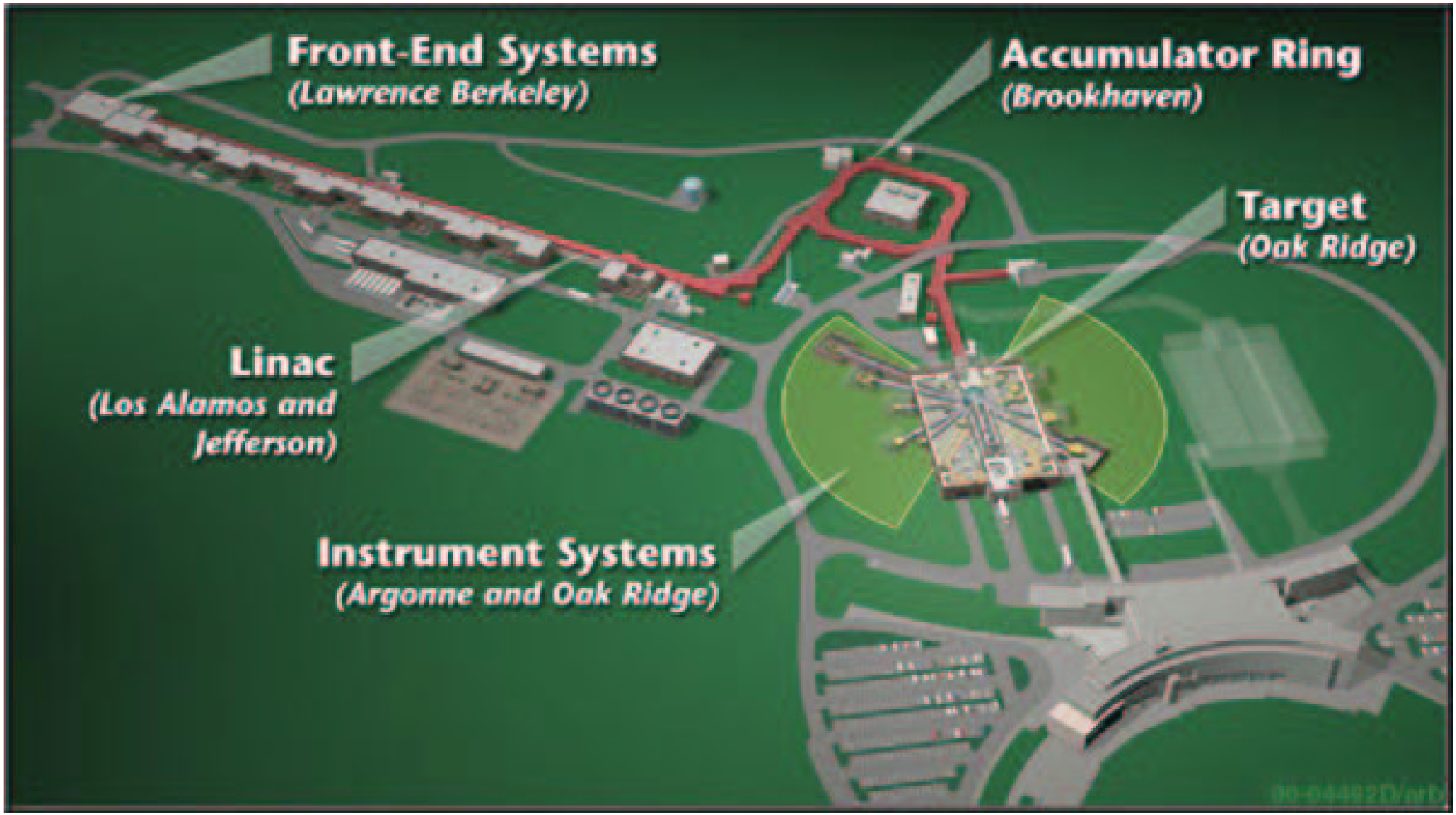
  Expect ~10 ν background events per year! (background reduced by r^{-2} = 1/10)

  Expect < 20 beam-off background events per year (DF lower by 100)

  Total background < 30

  S/B > 10 (for $\Delta m^2 \sim 0.3$ eV^2)

SNS Schematic



How the Nova sensitivity was calculated:

Code: a package written by Mike Shaevitz for APS Nu Study.
(includes osc. prob. code from S.Parke)

Purpose: Study relative contributions of Reactor, T2K, Nova
to atmospheric Δm^2 studies individually, in groups, as fn of time.

Agreement between Groups:
A meeting between representatives of the SuperBeams and Reactor
APS Study Groups (SW, JC, DM, BM/MD, GB, EB, MS, GF)
led to agreement on this code, statistical methods & presentatation layout.

How the code works, in general:

1) Generate data (osc. probs) for a given point in δ and $\sin^2\theta_{13}$ space.
2) Find the minimum χ^2 demanding $\delta=0$ but allowing θ_{13} and θ_{23} to vary
3) The 2σ limit curve is where the $\chi^2=4$

For a MiniBooNE CP Conserving signal:

1) Generate data (osc. probs) for a given point in δ and $\sin^2\theta_{13}$ space.
2) Add an additional oscillation signal w/ P=0.02 to both neutrino and antineutrino data
3) Find the minimum χ^2 demanding δ=0 but allowing θ_{13} and θ_{23} to vary also, acknowledge the additional signal of unkown size by allowing an extra systematic term, k_{MB}, to vary
   (contrained to a minimum of zero LSND signal)
   with a χ^2 penalty of $(k_{MB}/0.02)^2$
   k_{MB} is the same for neutrinos and antineutrinos
4) The 2σ limit curve is where the χ^2=4

For a CP Violating signal (known or unknown):

Same as above except that k_{MB} term is only applied to antineutrinos

Theoretical Justification for 3+2 .... examples from the last 6 months

THE STERILE NEUTRINO: FIRST HINT OF 4TH GENERATION FERMIONS?
By Stephen Godfrey, Shouhua Zhu. May 2004. 4pp. ** Temporary entry ** e-Print Archive: hep-ph/0405006

LARGE MIXING FROM SMALL: PSEUDODIRAC NEUTRINOS AND THE SINGULAR SEESAW.
By G.J. Stephenson,Jr. (New Mexico U.), T. Goldman (Los Alamos), B.H.J. McKellar, M. Garbutt (Melbourne U.),.
LA-UR-04-1736, Apr 2004. 26pp. Extension of hep-ph 0307245. e-Print Archive: hep-ph/0404015

TWO LIGHT STERILE NEUTRINOS THAT MIX MAXIMALLY WITH EACH OTHER AND MODERATELY WITH THREE ACTIVE NEUTRINOS.
By Wojciech Krolikowski (Warsaw U.),. IFT-04-7, Feb 2004. 12pp.
Published in Acta Phys.Polon.B35:1675-1686,2004
e-Print Archive: hep-ph/0402183

(3+2) NEUTRINO SCHEME FROM A SINGULAR DOUBLE SEESAW MECHANISM.
By K.L. McDonald, B.H.J. McKellar, A. Mastrano (Melbourne U.),. Jan 2004. 5pp.
e-Print Archive: hep-ph/0401241

SIMPLE MODEL FOR (3+2) NEUTRINO OSCILLATIONS.
By K.S. Babu, Gerhart Seidl (Oklahoma State U.),. OSU-HEP-03-15, Dec 2003. 12pp.
e-Print Archive: hep-ph/0312285

Doesn't Cosmology Rule Out 3+2 Models?

Nope.

Many proposals have been made to evade the cosmological limits.
For recent relevant articles (last 6 months) see...

Beacom, Bell & Dodelson, astro-ph/0404585
Hannestad, hep-ph/0404239
Gelmini,Palomares-Ruiz, & Pascoli. astro-ph/0403323
Olive, Skillman, astro-ph/0405588

And for a very nice review see
Abazajian, astro-ph/0205238